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DIFFICULTIES EXPERIENCED WITH THE AMES 15 MEGAWATT POWER SUPPLY

by

Forrest E. Gowen and Vaughn D. Hopkins

NASA. Ames Research Center,
Moffett Field, Calif~~ornia~~

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INTRODUCTION

The Mass Transfer Cooling and Aerodynamics Facility has recently put into operation two hypersonic wind tunnels. These wind tunnels use arc heaters to heat air to high enthalpy for simulation of flow conditions and heating rates around vehicles entering the earth's atmosphere at hypersonic speeds. Power for the arc heaters is provided by a 15 megawatt power supply furnished by Westinghouse. The purposes of this paper are to describe the power supply operational problems which have occurred and to indicate the solution to one of these problems.

POWER SUPPLY DESCRIPTION

This power supply is comprised of five identical three-megawatt modules. These modules can be connected together to provide 15 megawatts of D.C. power for five minutes or 5.66 megawatts for one hour with two hours off between runs.

A simple one line diagram of one module is shown in figure 1. All modules are fed from a common 6900 volt A.C. breaker. Components of each module are a saturable reactor for control, a rectifier transformer and the rectifiers. The A.C. current flowing through the saturable reactor is controlled by a silicon-rectifier bias-control circuit which can provide as much as 60 amps control current at 350 volts. The rectifier transformer has one primary winding and two separate secondary windings. One of these secondary windings is connected "delta" and provides power to one half of a module. The other secondary winding is connected "wye" and provides power to the other half of a module. Each of these secondary windings feeds a rectifier unit consisting of six Westinghouse ignitrons connected in a three-phase, full-wave bridge circuit. Following each rectifier unit is a D.C. filter comprised of a series inductance (with taps) and three parallel shunt circuits tuned to 360 cycles, 720 cycles, and 1080 cycles respectively. Following the filters, and not shown, are a series of switches for connecting the half modules in parallel or series. The arc-heater load, which is located in another building 1200 feet away from the power supply, can be connected to the five modules in any series or parallel combination.

The steady-state voltage-current characteristics of one half-module are shown in figure 2. Each half module is rated at 1200 amps and 1250 volts. The ten half modules can be connected in various series and parallel combinations to give as much as 1200 amps at 12500 volts or 12000 amps at 1250 volts.

OPERATIONAL PROBLEMS

The first operational problem is a large overshoot or undershoot of the load current upon arc initiation. The magnitude of this transient is indicated in figure 3. This type of transient behavior would not be important if the duration ~~was~~ were very short. Unfortunately, the starting transients with this power supply may persist for several seconds before decaying, or approaching, the preset load current. This long time-constant behavior results in two different problems. First, the overshoots persist so long that magnetic field coils or other equipment with limited current carrying ability and low heat sink capability can be destroyed. Second, an undershoot can cause the arc to be extinguished during start. This condition is aggravated by an occasional short-duration 60 cycle oscillation which may drop the current to near zero during the first or second oscillation.

The above starting transient behavior is believed to be associated with the characteristics of the saturable reactor. It is apparent from figure 3 that the amount of overshoot or undershoot is a strong function of the D.C. control current in the saturable reactor. The rise time of the current in the rectifier load circuit should be a function of the magnetic flux in the saturable reactor. This flux is dependent upon the level of the bias control current at the time the main breaker closes and the level of the residual megnetic flux from the previous run. Since the time constants of the main A.C. circuit and the D.C. control circuit are different it is expected that a proper timing of the closing of the bias contactor relative to the main A.C. breaker would control the overshoot or undershoot. In addition, to eliminate the influence of a variable residual magnetic flux the saturable reactor can be demagnetized after each run by reversing the D.C. control current. This will reverse the magnetic flux and provide a fixed flux condition for each start.

A test was set up to determine the feasability of using breaker timing and the above method of demagnetizing for controling the starting transient. The results of this test for one test condition are shown in figure 4 which shows a typical starting transient with proper timing after demagnetization. Figure 5 shows the required delay time for the A.C. breaker after the bias contactor is closed. If the delay time shown is used no overshoot or undershoot will occur for the entire range of load conditions available.

The results of this test have proven the practicality of using the above method for controlling the starting transient. A permanent system now being designed will include saturable reactor control current reversal prior to each run along with proper timing of breaker closing for all load conditions.

A second major problem is an unstable oscillation in voltage and current such as that shown in the oscillograph trace of figure 6. These oscillations may increase until the arc is extinguished. This type of instability occurs for some operating conditions when the power supply is connected to a Linde Model N4000 Arc Heater. The Linde arc heater is a high voltage heater with a vortex stabilized arc. This heater has operated over a wide range of operating conditions using moving-coil controlled rectifiers and with tap-changing transformer-controlled rectifiers without important arc stability problems. However, when operated at high air flow rates with the Ames 15 megawatt power supply the arc becomes unstable and extinguishes itself. This instability is characterized by the 2 to 5 cycle per second voltage and current fluctuation shown in figure 6. The indicated excursions in current would have been impossible if the power-supply characteristics were defined by the steady-state curve shown in figure 7. The preset operating point is noted on the steady-state curve and the typical transient excursions from this point are shown by the data points which were taken from an oscillograph record. This greatly reduced slope of the curve for the transient fluctuations indicate a greatly reduced output impedance which has a destabilizing influence upon arc operation.

Preliminary analysis of the theoretical characteristics of the power supply indicate that the low-frequency transient oscillations may be linked to a feedback from the load to the saturable reactor control circuit. (See for example reference 1.) Calculations are being made to determine feasibility of control circuit chokes to attenuate the low frequency oscillations as described in reference 1. In addition, other possible solutions to this problem are being considered and data are now being taken to determine the effect of various temporary "fixes".

CONCLUDING REMARKS

The problem of supplying power to a variety of arc loads is not as simple and straightforward as might be expected from a comparison of steady-state characteristics of arcs and power supplies. It is apparent ~~that~~ from the above problems, and others not covered by this note, that transient characteristics of power supplies with arc heater loads will have to be considered for satisfactory stable operation of high powered arcs.

REFERENCE

1. John, R. R., and others: Theoretical and Experimental Investigation of Arc Plasma-Generation Technology. Part I Applied Research on Direct and Alternating Current Electric Arc Plasma Generators, ASD TDR 62-729, Part I, Appendix C, Project No. 7360, Task No. 736001, Jan. 1963.

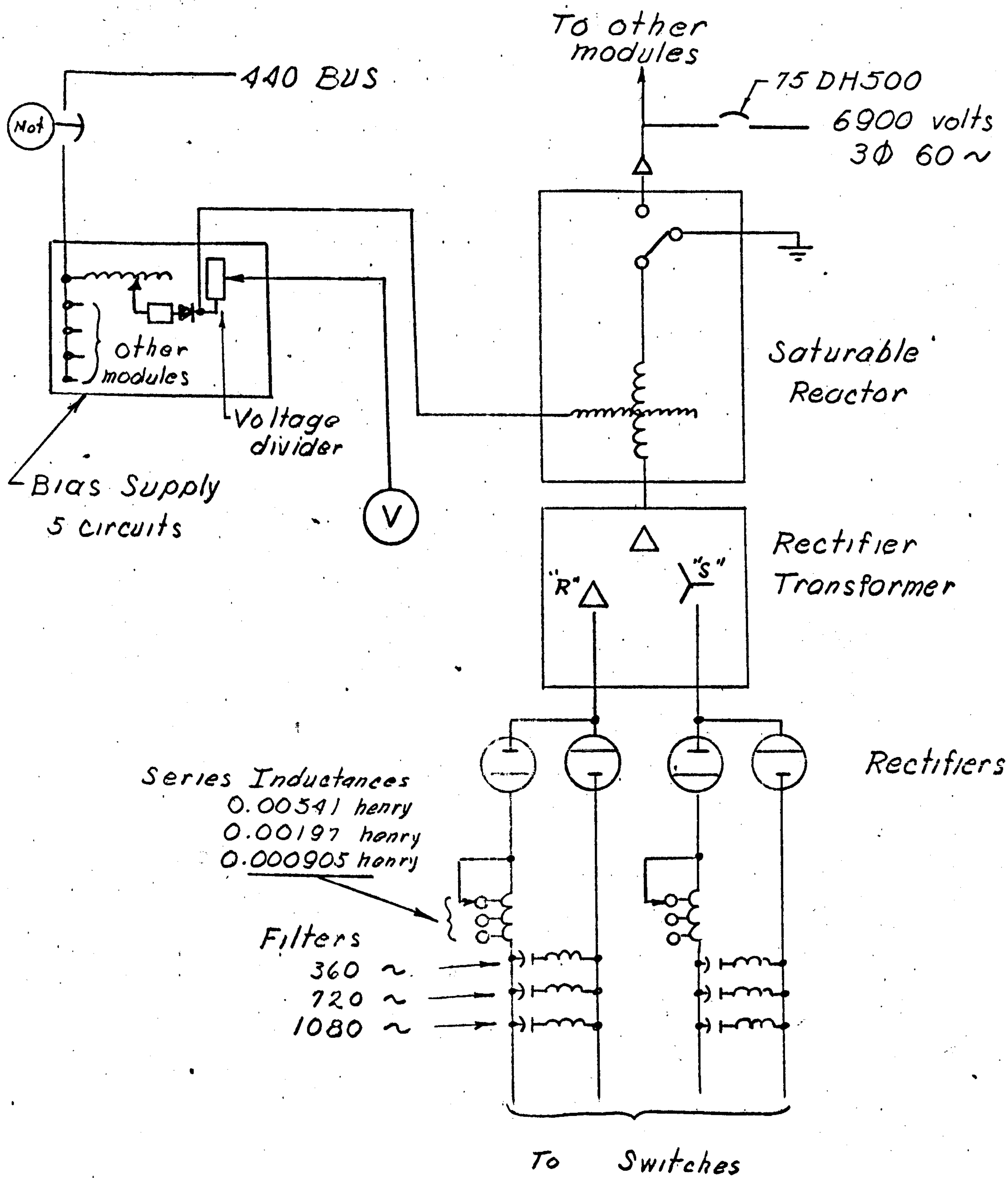

Figure 1 Ames 15 megawatt D.C. power supply
One line diagram for one module.

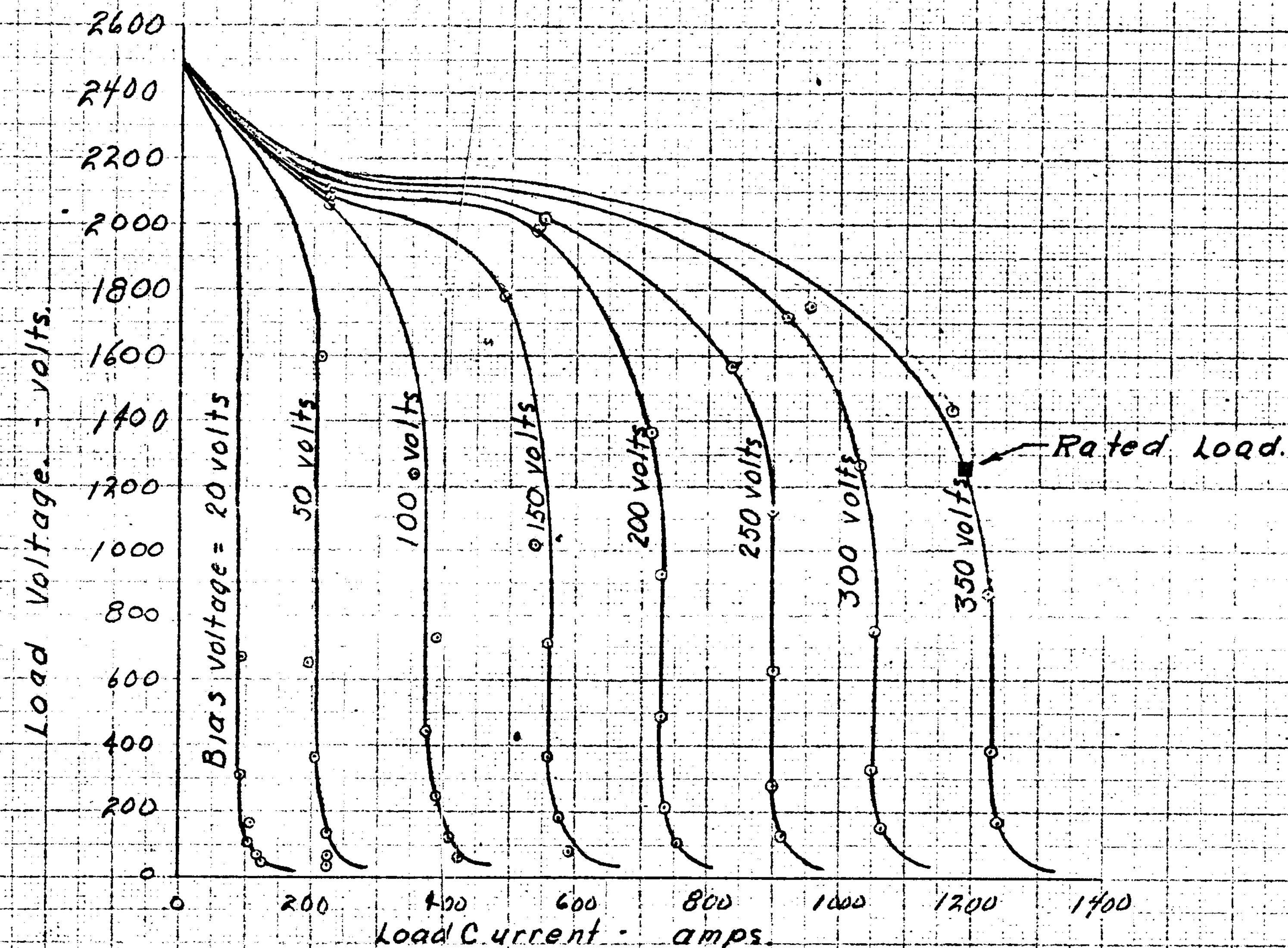

Figure 2. Steady state voltage-current characteristics of one half module of the Ames 15 megawatt D.C. power supply

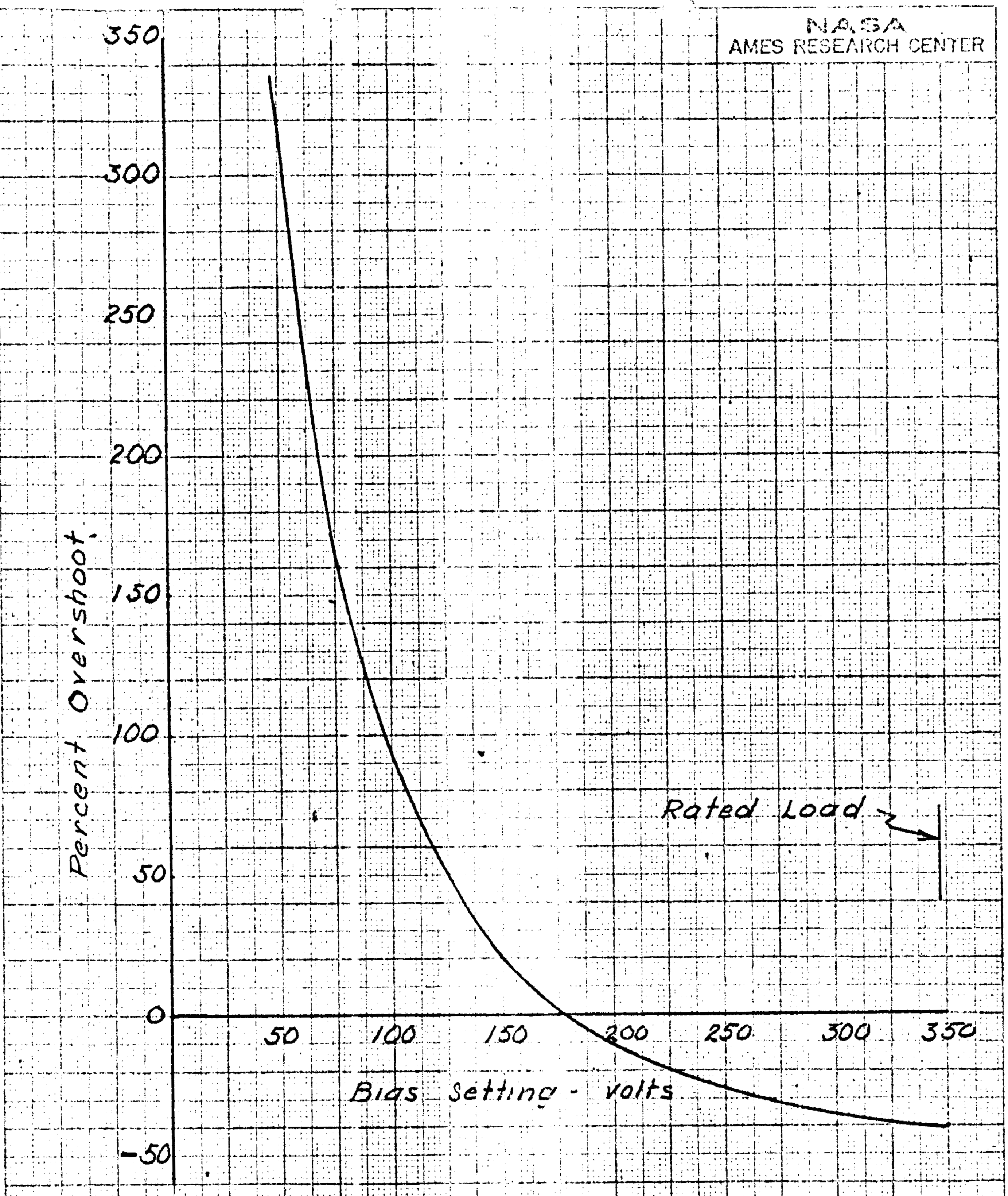

Figure 3 Power supply overshoot characteristics

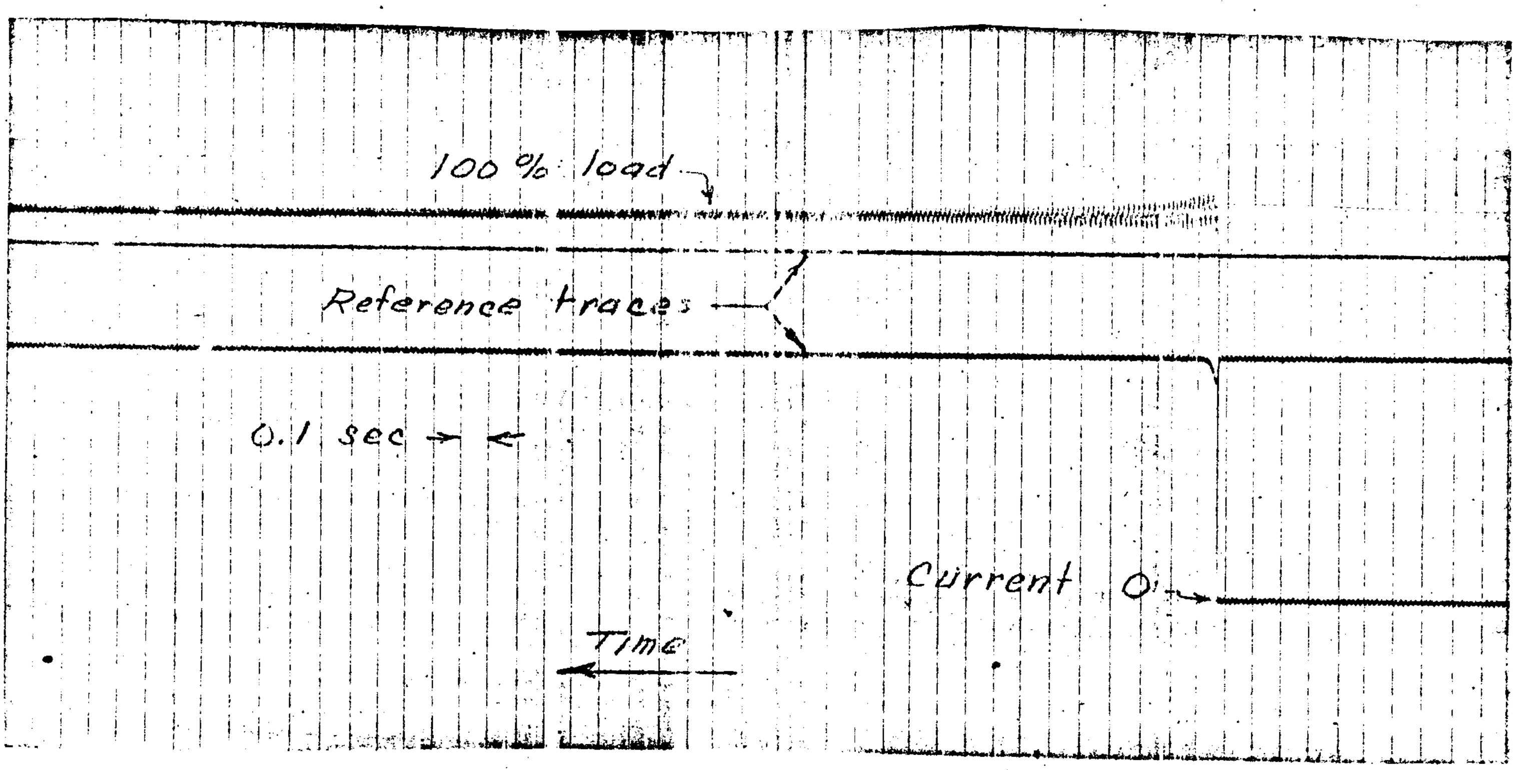

Figure 4. Time history of starting transient with proper breaker timing.

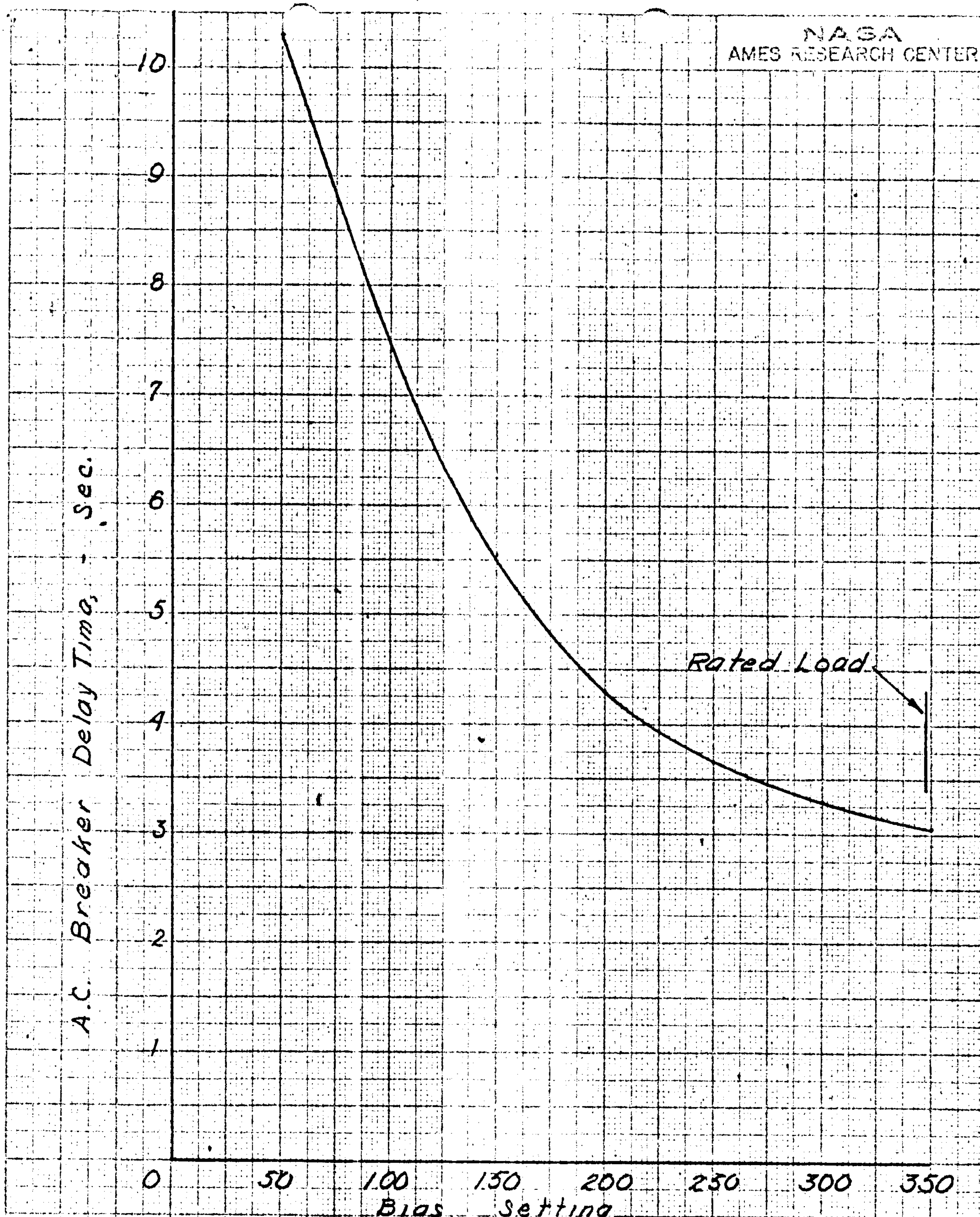

Figure 5. A.C. Breaker delay time vs bias setting

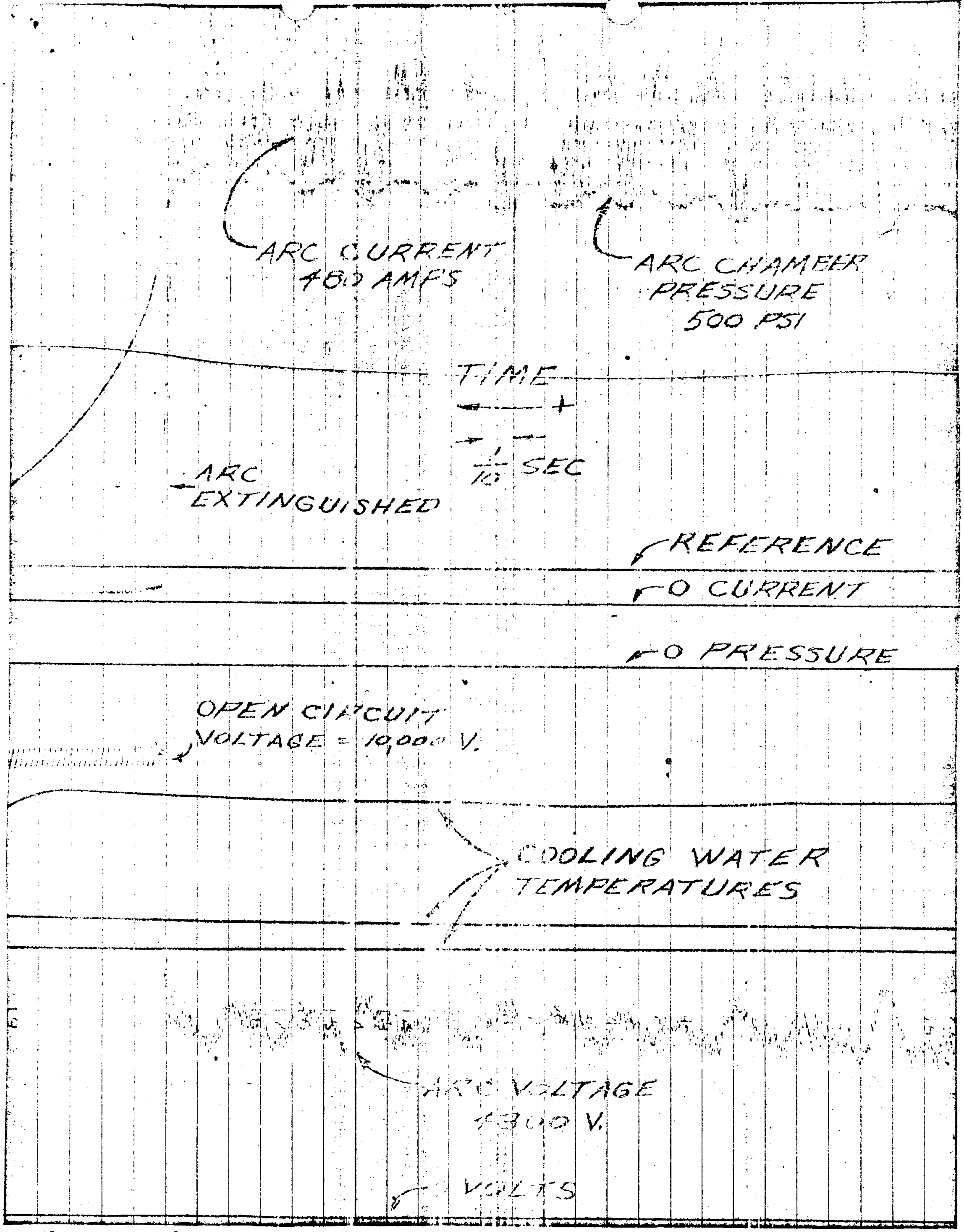

Figure 6 Oscillograph record of power supply output with Linde Model N4000 arc heater load.

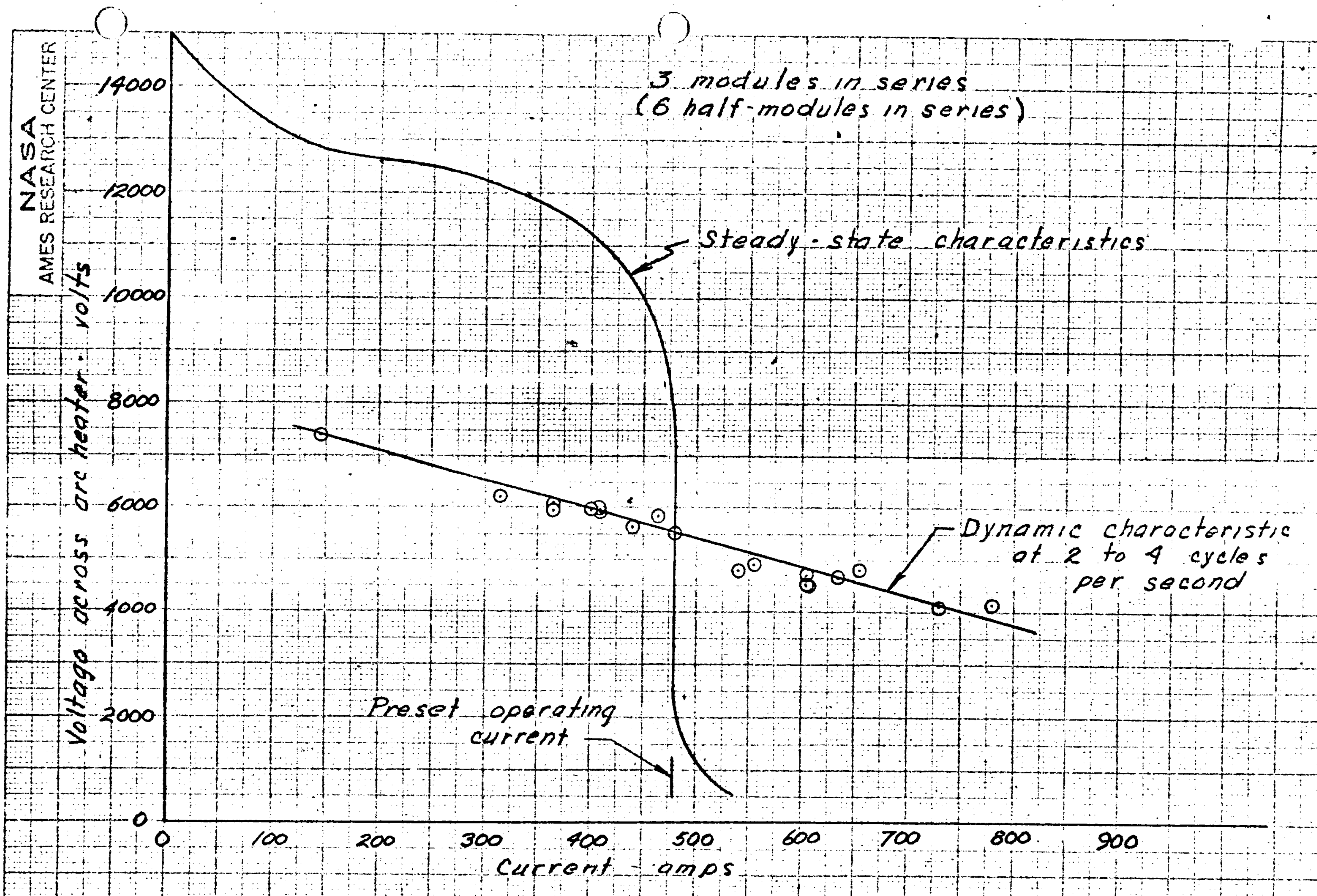

Figure 7.- Voltage-current characteristics of the power supply with a Linde model N 4000 arc heater load.